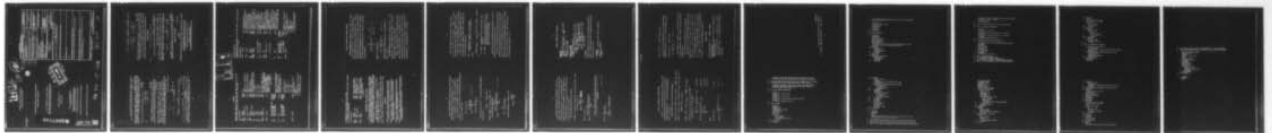


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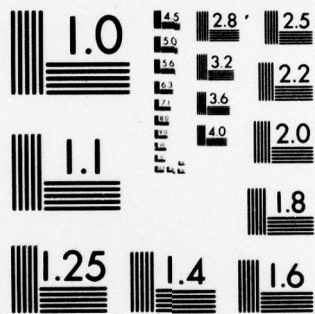
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LEAST SQUARES PREDICTION FOR MIXED AUTOREGRESSIVE MOVING AVERAGE TIME SERIES

By M. Joseph Newton and Marcello Pagano
Institute of Statistics, Texas A&M University and
Dept. of Biostatistics, Harvard University, U.S.A.

Technical Report No. M-2
February 1979

Texas A & M Research Foundation
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"Multiple Time Series Modeling and Time
Series Theoretic Statistical Methods"

Sponsored by the Office of Naval Research

Professor Emanuel Parzen, Principal Investigator

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Technical Report, No. M-2

Least Squares Prediction for Mixed Autoregressive Moving Average Time Series,

H. Joseph Newton and Marcello Pagano

Texas A&M University
Institute of Statistics
College Station, TX 77843

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Mixed time series, Toeplitz matrix, Modified Cholesky decomposition

A computer subroutine is given for computing predictors of any specified horizon's ahead.

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LEAST SQUARES PREDICTION FOR MIXED AUTOREGRESSIVE MOVING AVERAGE TIME SERIES

By H. Joseph Newton and Marcello Pagano

*Institute of Statistics, Texas A&M University and
Dept. of Biostatistics, Harvard University, U.S.A.*

Keywords: Mixed Time Series, Toeplitz Matrix, Modified Cholesky Decomposition

ISO Fortran

LANGUAGE

DESCRIPTION AND PURPOSE

Let $y(1), \dots, y(T)$ be a sample realization of a mixed autoregressive moving average process $y(t), t = 0, 1, \dots$ of order (p, q) , i.e., $y(t)$ satisfies

$$\sum_{j=0}^p a(j)y(t-j) = \sum_{k=0}^q b(k)e(t-k), \quad t = 0, 1, \dots$$

for constants $p, q, a(0) = b(0) = 1, a(1), \dots, a(p), b(1), \dots, b(q)$, where $e(\cdot)$ is a white noise time series of zero mean, uncorrelated random variables with variance σ^2 . The zeros of the complex polynomials $g(z) = \sum_{j=0}^p a(j)z^j$ and $h(z) = \sum_{k=0}^q b(k)z^k$ are assumed outside the unit circle.

Subroutine NORD calculates least squares predictors $y(t+v|t)$ of $y(t+v)$ given $y(1), \dots, y(t)$ for

$$v = v_p, \dots, v_L \text{ for } t = t_p, \dots, t_L. \quad (1)$$

NUMERICAL METHOD

The algorithm given by Pagano and Parzen (1973) (based on the work of Whittle (1963)) is used. Let $X(t) = \sum_{j=0}^p a(j)y(t-j)$, $t = p+1, \dots, T$.

Then the $X(\cdot)$ are a sample realization of a pure moving average process of order q and $X^T = (X(p+1), \dots, X(T))$ has the symmetric Toeplitz correlation matrix Γ where

$$\Gamma_{jk} = \begin{cases} 1 & j = k \\ \rho(|j-k|) & |j-k| = 1, \dots, q \\ 0 & |j-k| > q \end{cases}$$

$$\text{and } \rho(v) = \sum_{k=0}^q b(k)b(k+v) / \sum_{k=0}^q b^2(k) = R(|v|)/R(0), \quad |v| \leq q.$$

Let $\Gamma = L\Lambda L^T$ be the modified Cholesky decomposition (Wilkinson (1967)) of Γ , i.e., L is a unit lower triangular $(T-p) \times (T-p)$ matrix (L_{jk}) and D is a $(T-p) \times (T-p)$ diagonal matrix (D_{jj}) . Define $\tilde{\Gamma} = (e(p+1), \dots, e(T))$ by $\tilde{\Gamma} = X(t) - \sum_{k=1}^{T-p} L_{t-p-k} e(t-k)$, $t = p+1, \dots, T$, i.e., $\tilde{\Gamma} = \tilde{X}$.

Then $y(t+v|t) = X(t+v|t) - \sum_{j=1}^p a(j)y(t+j|t)$ where

$$X(t+v|t) = \begin{cases} \sum_{k=0}^q b(k)e(t+v-k), & v = 1, \dots, q \\ 0 & v > q \end{cases}$$

and $y(t|t) = y(t)$ if $t \leq p$.

Thus the algorithm essentially consists of finding successive rows of the matrix L , using as little storage space as possible. This is done by noting:

- 1) the k^{th} row of L has $n_k = \max(k - q - 1, 0)$ leading zero elements followed by $n_k = \min(k - 1, q)$ elements, followed by a 1, followed by $T - p - n_k - n_k - 1$ zeros. Thus only n_k elements need be stored for any row.

- 2) to find the k^{th} row of L , at most the previous q rows are necessary.

- 3) Bauer (1955) has shown that as k gets large, $L_{k,k-j} \rightarrow b(j)$ and $D_{kk} \rightarrow \sigma^2/R(0)$. Thus for a fixed δ , there should be an integer N such that

$$\begin{aligned} |L_{k,k-j} - b(j)| &< \delta \\ |D_{kk} - \sigma^2/R(0)| &< \delta \end{aligned} \quad (2)$$

for $j = 1, \dots, q, k \geq N$. Thus only the first N rows of L need be computed.

NORD calls auxiliary subroutine NORTN to find $e(p+1), \dots, e(T)$ using only a $(q+1) \times (q+1)$ work space for computing L . NORTN is designed so that it can be used also for performing Bauer's algorithm or to find the modified Cholesky decomposition of the symmetric Toeplitz matrix whose first row is $(1, \rho(1), \dots, \rho(q))$.

NORD is designed to perform prediction for pure autoregressive time series if $q = 0$ and for pure moving average time series if $p = 0$.

Subroutine MACV1 (M0, M1A, SIGSQ, R, M0, IFAULT)

Description: MACV1 calculates moving average autocovariances corresponding to moving average parameters.

Formal parameters

M0 Integer input: order of moving average
M1A Real Array (M0) input: moving average coefficients
SIGSQ Real input: variance of $\epsilon(\cdot)$
R Real Array (M0) output: autocovariances for lags 1, ..., M0
M0 Real output: variance of moving average
IFAULT Integer output: faulty indicator, equal to:
0 if proper execution
1 if $M0 < 1$

RESTRICTIONS, TIME, NECESSARY STORAGE

If the zeros of $h(z)$ are not outside the unit circle, the correlation matrix r is not positive definite. This is manifested by a diagonal element of its modified Cholesky decomposition becoming nonpositive. Subroutine MAORTH tests for this by checking for diagonal elements being $< \epsilon$ (specified in data statement). If one is found, IFAULT is set to 5 and execution stops.

Subroutine M0P0 requires $(p+1) + (q+4)(q+1) + 3T + MM$ storage locations. The number of operations is approximately $(t_L - p)(p+q) + M(q+1)/2 + (t_L - t_p + 1)[v_L p + q + (q-1) + \dots + \max(1, q - v_L + 1)]$, where M is the number of rows of L before convergence. M increases as the smallest zero of $h(z)$ approaches the unit circle.

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Outline of Algorithm for Subroutine MAORTH

Subroutine MAORTH is used to find a vector $\xi = (\xi(1), \dots, \xi(T))^T$, by $L\xi = Y$, where $Y^T = (Y(1), \dots, Y(T))$ is a sample realization of a moving average process of order q with coefficients $\beta(1), \dots, \beta(q)$ and noise variance σ^2 , and L is the $(T \times T)$ unit lower triangular matrix of the modified Cholesky decomposition $r_{q,T} = LDL^T$ of the $T \times T$ symmetric band Toeplitz correlation matrix $r_{q,T}$ of Y . Thus the (j, k) th element of $r_{q,T}$ is given by

$$(r_{q,T})_{jk} = \begin{cases} 1 & \text{if } j = k \\ \rho(|j - k|) & |j - k| = 1, \dots, q \\ 0 & |j - k| > q \end{cases}$$

where $\rho(v) = R(v)/R(0)$ and

$$R(v) = \sigma^2 \sum_{k=0}^{q-v} \beta(k)\beta(k+v), \quad v = 0, \dots, q$$

(Subroutine MACV1 calculates $R(0), R(1), \dots, R(q)$ given $q, \sigma^2, \beta(1), \dots, \beta(q)$)

Subroutine MAORTH can also be used to calculate $\sigma^2, \beta(1), \dots, \beta(q)$ if $R(0), R(1), \dots, R(q)$ are inputted. Thus if IOPTB = 1, the R 's are input while if IOPTB = 0, the β 's and σ^2 are input.

Further, one need not calculate the c 's if the subroutine is used only for Bauer's algorithm (IOPTB = 1). Thus if IOPTC = 1, the c 's are calculated (and the Y 's are input), while if IOPTC = 0, the c 's are not calculated (and the Y 's need not be inputted). The dimension of E and Y (the mnemonics for ϵ, Y) is IROMS1 which can be 1 if IOPTC = 0.

Finally, subroutine MAORITE can be used to merely find the modified Cholesky decomposition of $\Gamma_{q,T}$ by inputting $R(0)$, $R(1)$, ..., $R(q)$, 0, ..., 0, letting $NQ = T - 1$, $ITER9 = T$, $IOPTS = 1$, and $IOPTH = 0$.

Let $A = (A_{ij})$ be a real symmetric $(T \times T)$ matrix and $L = (L_{ij})$, $D = \text{diag}(d_1, \dots, d_T)$ be the factors in the Modified Cholesky decomposition of A , i.e., $A = LDL^T$. Then

$$\begin{aligned} L_{11} &= 1, d_1 = A_{11} \\ A_{ki} &= \sum_{j=1}^{i-1} d_j L_{kj} L_{ji} \\ L_{ki} &= \frac{A_{ki} - \sum_{j=1}^{i-1} d_j L_{kj} L_{ji}}{d_i} \quad i < k = 2, \dots, T \\ d_k &= A_{kk} - \sum_{j=1}^{k-1} d_j L_{kj} L_{kj} \end{aligned}$$

For $A = \Gamma_{q,T}$, $L_{ki} = 0$ if $k - i > q$; in fact the nonzero elements of row k of L are

$$L_{k, m_1+1}, \dots, L_{k, m_1+m_2}, L_{kk} = 1$$

where $m_1 = \max(k - q - 1, 0)$, $m_2 = \min(k - 1, q)$.

The equations given above become

$$L_{k, m_1+j} = \frac{\rho(k-m_1-j) - \sum_{i=m_1+1}^{m_1+j-1} d_i L_{ki} L_{ji}}{d_{m_1+j}}, \quad j = 1, \dots, m_2$$

$$d_k = 1 - \sum_{j=1}^{m_2} d_{m_1+j} L_{k, m_1+j}^2$$

From these equations it is possible to note:

$$L_{k, m_1+1} = \frac{\rho(k-m_1-1)}{d_{m_1+1}}$$

Thus in calculating row k of L and d_k , one needs only rows $m_1 + 2, \dots, m_1 + m_2 = k - 1$ of L and $d_{m_1+1}, \dots, d_{m_1+m_2}$, i.e., at most the previous q rows of L and the previous q elements of D . However,

$q + 1$ rows are stored so that the decomposition of $\Gamma_{q,q+1}$ can be obtained.

Let $NQ \equiv q$, $NQP1 \equiv q + 1$. Subroutine MAORITE uses the constant DK and the arrays $D(NQP1)$, $WKL(NQP1)$, $AL(NQP1)$, $NQP1$ to determine the rows of L and the diagonal elements of D :

Step 1: initialize $D(1) = 1$, $AL(1, 1) = 1$, $I = 1$, $NQP1$
Calculate $R(1) = R(1)/M9$, i.e. the autocorrelations

Step K:

Calculate $L_{k, m_1+1}, \dots, L_{k, m_1+m_2}, d_k$ and store in $WKL(1), \dots, WKL(M3)$,
 DK

If $K \leq NQP1$: put WKL into K^{th} row of AL , DK into $D(K)$, and go to next row

If $K > NQP1$: shift down by 1 the 2nd through $NQP1^{\text{th}}$ rows of AL and 2nd through $NQP1^{\text{th}}$ elements of D . Put WKL into $NQP1^{\text{th}}$ row of AL and DK into $D(NQP1)$.

Thus the key point of the subroutine is knowing where L_{LJ} and d_L are located in AL and D when calculating the K^{th} step.

If $K \leq NQ + 2$, no shifting of AL and D has been done since shifting is done after calculating WKL , DK and only for $K > NQ + 1$. Thus the I^{th} row of L is in the I^{th} row of AL and d_I is in $D(I)$. If $K = NQ + 2 + M$ the $NQ + 1$ rows of AL are the M^{th} through $(NQ + M)^{\text{th}}$ rows of L . In general then the I^{th} row of L and d_I are in the $(I - NQ)$ row of AL and in $D(I - NQ)$, where $NQ = \max(K - NQ - 2, 0)$.

It remains to determine where the j^{th} element of row I of L is located at step K . The elements of the i^{th} row of L that aren't identically zero or one are $L_{i, M_1}, \dots, L_{i, M_2}$ where $M_1 = \max(I - M_0, 1)$. They are stored in the first through $\min(I - 1, M_0)$ elements of row $(I - M_0)$ of AL at step K , i.e., $L_{i, M_1 + M_0 - 1}$ is in $AL(I - M_0, M_1)$ or $L_{i, J}$ is in $AL(I - M_0, J - M_0 + 1)$ at step K .

Thus the equations given above can be written:

For step $K \geq 2$: Let $M_1 = M_1 = \max(K - M_0 - 1, 0)$, $M_2 = M_2 = \min(K - 1, M_0)$, $M_3 = \max(K - M_0 - 2, 0)$.

$$WEL(1) = \frac{\rho(K - M_1 - 1)}{d_{M_1 + 1}} = \frac{R(K - M_1 - 1)}{D(M_1 + 1 - M_0)}$$

If $M_3 < 2$, go to d

$$WEL(J) = \frac{\rho(K - M_1 - J) - \sum_{I=1}^{J-1} d_{M_1 + J} L_{I, M_1 + J}^2}{d_{M_1 + J}}$$

$$= \frac{R(K - M_1 - J) - \sum_{I=1}^{J-1} D(M_1 + J - M_0) * WEL(I) * AL(M_1 + J - M_0, M_1 + J - \max(M_1 + J - M_0, 1) + 1)}{D(M_1 + J - M_0)}$$

$J = 2, \dots, M_3$

$$*MK = 1 - \sum_{J=1}^{M_3} d_{M_1 + J} L_{I, M_1 + J}^2$$

$$= 1 - \sum_{J=1}^{M_3} D(M_1 + J - M_0) * WEL(J) * WEL(J)$$

Summary of MAORTH (Let E represent c)

Initialize:
 $EFS = 1.E - 10$
 If $IOPTB = 0$, calculate M_0 , $R(1)$, ..., $R(M_0)$ via MACV1
 Store $\rho(1)$, ..., $\rho(M_0)$ in $R(1)$, ..., $R(M_0)$
 $D(1) = 1$
 $AL(1, 1) = 1$, $I = 1$, $MQP1$
 If $IOPTB = 1$, $E(1) = Y(1)$
Do 130 K = 2, ITERB
Calculate WEL , DK
 If $IOPTB = 1$, calculate $E(K)$
 If $DK < EFS$, Γ not positive definite. Go to 199
 $K < MQP1$: put WEL , DK into AL , D . Go to 130
 $K > MQP1$: do shifting
 $IOPTB = 1$: check convergence of rows of AL
 Yes: Form $BETA$, $SIGSQ$. Go to 150
 No: Go to 130
 $IOPTB = 0$: check convergence of AL to $BETA$
 Yes: Go to 150
 No: Go to 130
 130 CONTINUE
 If Loop is performed for all K , then the algorithm is done except if
 $IOPTB = 1$ in which case $BETA$, $SIGSQ$ are assigned values from last row of AL and D and Go to 199
 150 CONTINUE
 If $IOPTB = 1$, calculate the rest of the E 's using $BETA$
 199 Reform autocovariances
 RETURN

Outline of Algorithm for Subroutine MIXPD

Let $Y(1), \dots, Y(T)$ be a sample realization of length T of a mixed autoregressive moving average time series of order (p, q) with autoregressive parameters $\alpha(1), \dots, \alpha(p)$ and moving average parameters $\beta(1), \dots, \beta(q)$, and σ^2 .

Subroutine MIXPD calculates the least squares predictors

$$\begin{aligned} YPD(1) &= Y(t_f + v_f | t_f), \quad YPD(2) = Y(t_f + v_f + 1 | t_f), \dots, \quad YPD(N1) = Y(t_f + v_f | t_f), \\ YPD(N1 + 1) &= Y(t_f + 1 + v_f | t_f + 1), \quad YPD(N1 + 2) = Y(t_f + 1 + v_f + 1 | t_f + 1), \dots, \\ YPD(2^*N1) &= Y(t_f + 1 + v_f | t_f + 1), \end{aligned}$$

;

$$YPD(N2 - 1)^*N1 + 1 = Y(t_f + v_f | t_f), \dots, \quad YPD(NN) = Y(t_f + v_f | t_f),$$

where $N1 = v_f - v_f + 1$, $N2 = t_f - t_f + 1$, $NN = N1^*N2$.

The predictor $Y(t + v | t)$ is given by

$$Y(t + v | t) = \begin{cases} X(t + v | t) - \sum_{j=1}^p \alpha(j)Y(t + v - j | t) & p \neq 0, q \neq 0 \\ - \sum_{j=1}^p \alpha(j)Y(t + v - j | t) & p \neq 0, q = 0 \\ X(t + v | t) & p = 0, q \neq 0 \\ 0 & p = 0, q = 0 \end{cases}$$

where:

$$(a) \quad Y(t | a) = Y(t)$$

$$\text{if } t \leq a$$

$$(b) \quad X(t + v | t) = \begin{cases} \sum_{k=1}^q \beta(k) \epsilon(t + v - k) & v = 1, \dots, q \\ 0 & v > q \end{cases}$$

$$(c) \quad \xi = (\epsilon(p + 1), \dots, \epsilon(T))^T = L_{q, T-p}^{-1} \bar{X}, \text{ where}$$

$L_{q, T-p}$ is the unit lower triangular matrix in the modified Cholesky decomposition of the $(T - p) \times (T - p)$ correlation matrix $\Gamma_{q, T-p} \bar{X}$.

$$(d) \quad \bar{X} = (X(p + 1), \dots, X(T))^T, \text{ where}$$

$$X(t) = \sum_{j=0}^p \alpha(j)Y(t - j), \quad t = p + 1, \dots, T.$$

Note that $NPP1 = p + 1$ and $NQP1 = q + 1$ are input rather than p and q so that the dimension of $ALPHA = \alpha$ and $BETA = \beta$ can't be zero without stopping execution.

If $q = 0$, the $X(t + v | t)$ (and thus the ϵ 's) are not needed.

The predictors $Y(t + v | t)$ satisfy a difference equation for fixed t .

$$\text{Thus } Y(t + 1 | t), \dots, Y(t + v - 1 | t), X(t + 1 | t), \dots, X(t + v - 1 | t),$$

$$Y(t | t) = Y(t), \dots, Y(t - p + 1 | t) = Y(t - p + 1), \text{ and } \epsilon(t - q + 1),$$

$$\dots, \epsilon(t) \text{ are required to calculate } Y(t + v_f | t). \text{ If } t = q + 1 \leq p + 1$$

or $t - p + 1 < 1$ these values cannot be obtained. This is also true if

$t > T$. Thus if $t < p + q$ or $t < p$ or $t > T$ or $p + q = 0$, the predictors

$Y(t + v_f | t), \dots, Y(t + v_L | t)$ are assigned the value zero.

Summary of MIXPD

If $NQ \neq 0$ calculate $E(NP + 1), \dots, E(NOBS)$ via MAORTH

Do $150 \text{ NT} = \text{NT}, \text{NTL}$

If $\text{NT} < NP + NQ$ or $\text{NT} < NP$ or $\text{NT} > T$ or $NP + NQ = 0$ set predictors equal to zero and go to 150

If $NP \neq 0$ put $Y(\text{NT} - NP + 1), \dots, Y(\text{NT})$ into $X(1), \dots, X(NP)$.

Calculate $Y(\text{NT} + 1 | \text{NT}), \dots, Y(\text{NT} + \text{NVL} | \text{NT})$ and store in $X(NP + 1),$

$\dots, X(NP + \text{NVL})$.

Put X(NP + NVF), ..., X(NP + NVL) into YPD((NT - NTF)*NI + 1),
 ..., YPD((NT - NTF + 1)*NI), where NI = NVL - NVF + 1.
 150 CONTINUE

```

      SUBROUTINE MXPD(NPP1,NQP1,ALPHA,BETA,SIGSQ,NOBS,Y,DEL,NTF,
C      INTL,NVF,NVL,NN,IROWS1,IROWS2,AL,D,WKL,R,R0,E,X,YPD,IFAU
C      LT)
C      THIS SUBROUTINE CALCULATES LEAST SQUARES PREDICTORS FOR A MIXED
C      AUTOREGRESSIVE MOVING AVERAGE PROCESS OF ORDER (NP,NQ)
C
C      DIMENSION ALPHA(NPP1),BETA(NQP1),Y(NOBS),AL(IROWS1,IROWS1),
C      ID(IROWS1),WKL(NQP1),R(NQP1),E(IROWS2),X(NOBS),YPD(NN)
C      DATA ZERO,IOPTB,IOPTC/0.0,0,1/
C
C      TEST FOR INVALID PARAMETERS
C
C      IFAULT=1
C      IF(NPP1.LT.1) GO TO 160
C      IFAULT=2
C      IF(NQP1.LT.1) GO TO 160
C      IFAULT=3
C      IF((INTL-NTF+1)*(NVL-NVF+1).GT.NN) GO TO 160
C      IFAULT=4
C      IF(IROWS1.LT.NQP1) GO TO 160
C
C      FIND E ARRAY
C
C      NQ=NQP1-1
C      NP=NPP1-1
C      NPPNQ=NP+NQ
C      IF(NQ.EQ.0) GO TO 40
C      NX=NOBS-NP
C      DO 20 I=1,NX
C      NPP1=NP+I
C      C=Y(NPP1)
C      DO 10 J=1,NP
C      NPP1M=NPP1-J
C      C=C+ALPHA(J)*Y(NPP1M)
10      CONTINUE
C      X(I)=C
20      CONTINUE

```

```

C      CALL MAORTH(IOPTR,IOPT,E,NQ,DEL,NX,NX,X,BETA,SIGSQ,IROWS1,
C      1R,R0,WKL,D,AL,E,IF1)

```

```

C      IFAULT=5
C      IF(IF1.EQ.5) GO TO 160
C      DO 30 I=1,NX
C      N1=NOBS-I+1
C      N2=N1-NP
C      E(N1)=E(N2)
C 30    CONTINUE

```

```

C      FIND PREDICTORS
C

```

```

C 40    CONTINUE
C      N1=NVL-NVF+1
C      N2=NP+NVF
C      DO 150 NT=NTF,NTL
C      N3=(NT-NTF)*N1
C      NTEMP1=NT-NP-NQ
C      NTEMP=NT-NP
C      IF((NFPNQ.EQ.0).OR.(NT.LT.1).OR.(NT.GT.NOBS)) GO TO 55
C      IF((NP.NE.0).AND.(NT.LT.NPPNQ)) GO TO 55
C      GO TO 60
C 55    CONTINUE
C      DO 50 I=1,N1
C      N3PI=N3+I
C      YPD(N3PI)=ZERO
C 50    CONTINUE
C      GO TO 150
C 60    CONTINUE
C      IF(NP.EQ.0) GO TO 80
C      DO 70 I=1,NP
C      N4=NTEMP+I
C      X(I)=Y(N4)
C 70    CONTINUE

```

```

C 80    CONTINUE
C      DO 130 NV=1,NVL
C      C=ZERO
C      IF((NQ.EQ.0).OR.(NV.GT.NQ)) GO TO 100
C      NTPNV=NT+NV
C      IF((NP.EQ.0).AND.(NTPNV.LE.NQ)) GO TO 100
C      DO 90 K=NV,NQ
C      KK=NTPNV-K
C      C=C+BETA(K)*E(KK)
C 90    CONTINUE
C 100   CONTINUE
C      NPPNV=NP+NV
C      IF(NP.EQ.0) GO TO 120
C      DO 110 I=1,NP
C      NP1=NPPNV-I
C      C=C-ALPHA(I)*X(NP1)
C 110   CONTINUE
C 120   CONTINUE
C      X(NPPNV)=C
C 130   CONTINUE
C      DO 140 NV=1,N1
C      N3PNV=N3+NV
C      N5=N2+NV-1
C      YPD(N3PNV)=X(N5)
C 140   CONTINUE
C 150   CONTINUE

```

```

C      IFAULT=0
C 160   CONTINUE
C      RETURN
C      END
C      SUBROUTINE MAORTH(IOPTR,IOPT,E,NQ,DEL,ITERS,IROWS1,Y,BETA,
C      1SIGSQ,IROWS2,R,R0,WKL,D,AL,E,IFAU)

```

```

C      THIS SUBROUTINE CALCULATES THE MODIFIED CHOLESKY FACTORS OF THE
C      ITERS ORDER CORRELATION MATRIX FOR A MOVING AVERAGE PROCESS OF
C      ORDER NQ. IT IS USED TO CALCULATE THE CORRESPONDING COEFFICIENTS
C      AND/OR AN ORTHOGONAL TRANSFORMATION OF INPUTTED MOVING AVERAGE DATA.
C

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```

        DIMENSION Y(IROWS1),BETA(NQ),R(NQ),WKL(NQ),D(IROWS2),
        1AL(IROWS2,IROWS2),E(IROWS1)
        DATA ONE/1.0/
        DATA EPS/1.E-10/
C
C     EPS IS CRITERION FOR TESTING FOR ZERO DIAGONAL
C
C     TEST FOR INVALID PARAMETERS
C
        IF(AULT=1
        IF(NQ.LT.1) GO TO 299
        IF(AULT=2
        IF((IOPTB.NE.0).AND.(IOPTB.NE.1)) GO TO 299
        IF(AULT=3
        IF((IOPTB.NE.0).AND.(IOPTB.NE.1)) GO TO 299
        IF(AULT=4
        IF(IROWS2.LE.NQ) GO TO 299
C
C     AUTOCORRELATIONS AND INITIALIZATION
C
        IF(IOPTB.EQ.0) CALL MACV1(NQ,BETA,SIGSQ,R,R0,IF1)
        D(1)=ONE
        NQP1=NQ+1
        DO 5 I=1,NQ
            R(I)=R(I)/R0
        5 CONTINUE
        DO 10 I=1,NQP1
            AL(I,I)=ONE
        10 CONTINUE
        IF(IOPTB.EQ.1) E(1)=Y(1)
C
C     ROW K OF FACTORIZATION
C
C     M1 IS NUMBER OF LEADING ZEROS
C     M3 IS NUMBER OF ELEMENTS TO CALCULATE
C     MR IS SHIFTING FACTOR IN STORAGE OF PREVIOUS ROWS
C     INDD+J-1 IS ROW NUMBER OF AL FOR CALCULATING WKL(J)
C

```

```

        DO 130 K=2,ITERS
        M1=MAX0(K-NQ-1,0)
        M3=MIN0(K-1,NQ)
        INDR=K-M1-1
        MR=MAX0(K-NQ-2,0)
        INDD=M1+1-MR
        WKL(1)=R(INDR)/D(INDD)
        IF(M3.LT.2) GO TO 40
        DO 30 J=2,M3
            JM1=J-1
            INDR1=INDR-JM1
            C=R(INDR1)
            INDLR=INDD+JM1
            M4=-MAX0(M1+J-NQ,1)+M1+1
            DO 20 I=1,JM1
                INDD1=INDD+I-1
                INDL1=M4+I
                C=C-D(INDD1)*WKL(I)*AL(INDLR,INDL1)
        20 CONTINUE
            WKL(J)=C/D(INDLR)
        30 CONTINUE
        40 CONTINUE
        DK=ONE
        DO 50 J=1,M3
            INDD=M1+J-MR
            DK=DK-D(INDD)*WKL(J)*WKL(J)
        50 CONTINUE
        IF(IOPTB.EQ.0) GO TO 65
        C=Y(K)
        DO 60 I=1,M3
            INDWKL=M3-I+1
            INDE=K-I
            C=C-WKL(INDWKL)*E(INDE)
        60 CONTINUE
        E(K)=C

```

```

65  CONTINUE
    IFAULT=5
    IF(DK.LT.EPS) GO TO 199
    IF(N.GT.NQP1) GO TO 80
    D(K)=DK
    DO 70 I=1,NQ
        AL(K,I)=WKL(I)
70  CONTINUE
    GO TO 130
80  CONTINUE
    DO 82 I=1,NQ
        IP1=I+1
        D(I)=D(IP1)
        DO 81 J=1,NQ
            AL(I,J)=AL(IP1,J)
81  CONTINUE
82  CONTINUE
    D(NQP1)=DK
    DO 83 I=1,NQ
        AL(NQP1,I)=WKL(I)
83  CONTINUE
C
C  DEL IS CONVERGENCE CRITERION
C
    IF(IOPTR.EQ.0) GO TO 110
    DO 90 I=1,NQ
        IF(ABS(AL(NQP1,I)-AL(NQ,I)).GE.DEL) GO TO 130
90  CONTINUE
    IF(R0*ABS(D(NQP1)-D(NQ)).GE.DEL) GO TO 130
    DO 100 I=1,NQ
        INDWKL=NQ-I+1
        BETA(I)=WKL(INDWKL)
100 CONTINUE
    SIGSQ=R0*D(NQP1)
    IFAULT=0
    GO TO 150

```

```

110 CONTINUE
    DO 120 I=1,NQ
        INDB=NQ-I+1
        IF(ABS(WKL(I)-BETA(INDB)).GE.DEL) GO TO 130
120 CONTINUE
    IF(ABS(D(NQP1)*R0-SIGSQ).LT.DEL) GO TO 150
130 CONTINUE
    IFAULT=6
    IF(IOPTR.EQ.0) GO TO 199
    DO 140 I=1,NQ
        INDWKL=NQ-I+1
        BETA(I)=WKL(INDWKL)
140 CONTINUE
    SIGSQ=R0*DK
    GO TO 199
150 CONTINUE
    IFAULT=0
    IF(IOPTE.EQ.0) GO TO 199
    IF(K.EQ.ITER5) GO TO 199
    KP1=K+1
    DO 170 J=KP1,ITER5
        C=Y(J)
        DO 160 I=1,NQ
            INDE=J-I
            C=C-BETA(I)*E(INDE)
160 CONTINUE
        E(J)=C
170 CONTINUE
    IFAULT=0
199 CONTINUE
    DO 200 I=1,NQ
        R(I)=R(I)*R0
200 CONTINUE
299 RETURN
    END
    SUBROUTINE MACV1(NQ,BETA,SIGSQ,R,R0,IFAU)

```

```

C
C THIS SUBROUTINE CALCULATES AUTOCOVARIANCES OF A MOVING AVERAGE
C PROCESS OF ORDER NQ GIVEN ITS COEFFICIENTS AND RESIDUAL VARIANCE.
C
  DIMENSION BETA(NQ),R(NQ)
  DATA ONE /1.0/
  IFAULT=1
  IF(NQ.LT.1) GO TO 40
  C=ONE
  DO 10 I=1,NQ
    C=C+BETA(I)*BETA(I)
10  CONTINUE
  R0=SIGSQ*C
  DO 20 IV=1,NQ
    NQMIV=NQ-IV
    C=BETA(IV)
    DO 30 I=1,NQMIV
      IVPI=IV+I
      C=C+BETA(I)*BETA(IVPI)
30  CONTINUE
    R(IV)=C*SIGSQ
20  CONTINUE
C
C
40  IFAULT=0
    RETURN
    END

```